Part III

Maritime Forests and Climate Change

Chapter 11

Predicting Coastal Retreat in the Florida Big Bend Region of the Gulf Coast under Climate Change Induced Sea-Level Rise

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Summary

Many wildlife preserves and refuges in coastal areas of our nation are slowly being inundated by rising sea-level. Land elevation and tidal flooding are key factors controlling the extent and zonation of coastal habitats. Warming of our global environment threatens to speed the rate of sea-level rise and perhaps further amplify the detrimental effects of tropical storms, droughts, and lightning fires. A field and modeling study was conducted to determine the current status of emergent vegetation and surficial hydrology and to predict marsh transgression under rising sea-level. Field surveys were conducted to relate vegetation cover and ecotones to surface elevation and tidal inundation. A regional site application of a GIS-based simulation model, WETLANDS, was developed to predict ecosystem response to changing sea-level conditions on a coastal reach of the Big Bend region in northwest Florida. The WETLANDS model contains functional probabilities of community tolerance to flooding conditions that dictate the rate and process of ecological succession and coastal retreat. Map information of hypsography and bathymetry of the study area were digitized and interpolated to construct a digital elevation model. Classified thematic mapper imagery of aquatic and terrestrial habitat at a community level was used to initialize model simulation by vegetative type. Model simulations were generated to predict a likelihood index of habitat change and conversion under different scenarios of sea-level rise. The WETLANDS model was applied to track the process and pattern of coastal inundation over space and time for low, mid, and high sea-level rise projections of 15, 50, and 95 cm over the next century. Model results indicated that major portions of this coastal zone will be permanently inundated by 2100, bringing about a combined migration of marsh habitat and displacement of forest habitat. Results show that lowland pine forests will undergo retreat on the order of thousands of hectares over the 21st century. Coastal marsh extent may actually increase slightly as a function of the low lying topography. Socioeconomic implications may be nominal for this area given its remote and fairly undeveloped and protected coast-

line. The model offers a technological tool for research and policy purposes that allows for effective land and water management, risk assessment, and cumulative impact analysis of wetland systems and landscapes.

11.1 Current Status and Stresses

Coastal communities worldwide are threatened by rising global sea-level in part contributed by human-induced causes related to fossil fuel consumption and increasing carbon dioxide concentrations in the atmosphere known as the "greenhouse effect." Many believe that these greenhouse gases may be contributing to warming of surface air and sea temperatures sufficient to accelerate sea-level rise, increase tropical storm intensity (Emanuel 1987), and alter regional climate patterns (Giorgi et al. 1994) commonly referred to as "climate change." Coastal margins are most vulnerable to all these potential impacts and interactions of climate variability and change (Boesch et al. 2000).

Sea-level has reportedly been rising since the last ice age (15,000 B.P.) and over the last century by as much as 1 – 2 mm/year (Gornitz, 1995). The latest Intergovernmental Panel on Climate Change (IPCC 1996) has projected a 50 cm rise in average global eustatic sea-level by year 2100 within a probable range of 15 – 95 cm given some uncertainties (Watson et al. 1996). Other conservative estimates by the U.S. Environmental Protection Agency indicate that global warming will likely raise sea-level by at least 42cm by 2100 (4.2 mm/yr, Titus and Narayanan, 1995).

These sea-level projections, however, do not consider increases in relative sea-level by region which will be affected by local factors other than warming sea temperatures (e.g., land subsidence). Gulf of Mexico coastal wetlands, in particular, have shown high rates of land subsidence attributed to soil decomposition and compaction, deep fluid extraction, and the lack of allochthonous sediment deposition. Relative sea-level is the effective change in the land/water datum relationship at a given site that includes both the eustatic sea-level change condition and changes in surficial elevation and accretion (Stevenson et al., 1986; Cahoon et al., 1998). For example, because of rapid subsidence, the Mississippi River delta region demonstrates relative sea-level rise rates of 10 mm/yr, tenfold greater than current eustatic sea-level rise (Penland and Ramsey, 1990, Turner, 1991; Gornitz, 1995).

As sea-level rises, flooding and salinity intrusion increase with slope at the coastal interface. Tidal marshes demarcate the boundary of tidal exchange though local conditions may dictate the actual height relative to tidal range. Coastal salt marshes, in general, exhibit fairly distinct zonation patterns grossly determined by the range and frequency of tidal inundation (Johnson and York, 1915; Jackson, 1952; Kurz and Wagner, 1957; Adams, 1963). The fate of persisting marshes depends on their ability to keep pace with relative sea-level rise through accretion by a combination of root production and organic and/or inorganic deposition and to tolerate any changes in soil salinity. Freshwater forest communities abutting marsh zones must likewise tolerate the increase in tidal influence or succumb to marsh migration upslope. The ability to predict coastal transgression from sea-level rise depends on the slope and height of the coastal landform and belowground processes and rates of elevation change. Because of the low relief of most gulf coast tidal marshes, rather small increases in sea-level could affect large expanses of the coastal zone.

Predicting the fate of our shorelines and coastal ecosystems is confounded by the diverse set of environmental forces and gradients that differ for each physical and biological setting. Areas along the gulf coast, for example, share the Gulf of Mexico but have different tidal regimes, energies and amplitudes, as well as different ecosystems, tropical and temperate. The frequency, periodicity, and intensity of tropical storm landfalls likewise varies across the Gulf basin. The degrees of coastal development and protection that have been applied by state and county as dictated by population, port facilities, or other priorities also differ. Detailed case studies of representative settings are needed to elucidate the specific effects and implications of climate change on our coastal resources. We reviewed the impact of probable rates of sea-level rise on the coastal wetlands of the Big Bend region of northwest Florida including St. Marks National Wildlife Refuge based on field surveys and simulation models. We considered socioeconomic implications and coping strategies that may reasonably minimize societal costs and consequences.

11.2 Regional Site Application, Big Bend Region, Florida

Tidal marshes of the Big Bend region of northwest Florida cover a 250 km stretch of coastline from

Panacea to Tarpon Springs encompassing an area estimated at 65,000 ha (Raabe et al, 1996). This coastal reach is characterized by low wave energy, semi-diurnal tides, microtidal range, low relief, and sharp vegetation zones and ecotones. A typical marsh is prominently dominated by black needlerush, *Juncus roemerianus*, interspersed with barren sand flats, and bounded by cordgrass, *Spartina alterniflora,* on tidal creeks and flats at low elevations and a diverse high marsh community at upper elevations along a forest ecotone (Figure 1). Marsh extent is usually no more than several kilometers wide, exhibiting a rather subtle elevation change of less than a meter rise from shore to coastal forest edge. Figure 2 depicts the distribution of wetland and upland habitats across the study area taken from thematic mapper imagery at 30 m pixel resolution.

Figure 1. Aerial view of typical saltmarsh and coastal pine/palmetto zones of St. Marks National Wildlife Refuge, Florida.

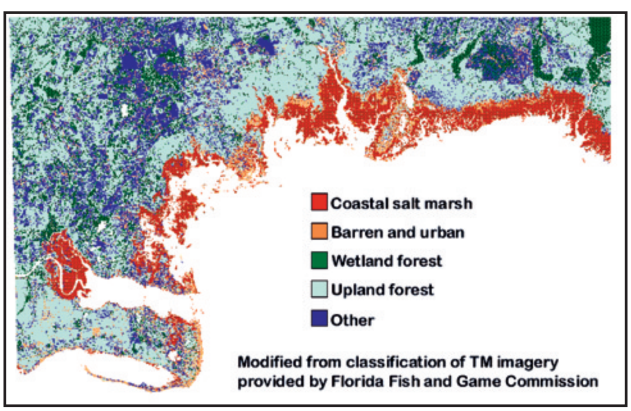

Figure 2. Habitat map of Big Bend coastal region including the boundary area of St. Marks National Wildlife Refuge south of Tallahassee, Florida.

Wave energy is classified as “zero” from St. Marks River east along the central Florida coastline to Cedar Key, Florida, and moderate from St. Marks River west to Apalachicola, Florida (Tanner, 1960). This coastal reach displays a low-relief topography of less than 1% (Coultas and Gross, 1975) that allows direct exchange of tidal ebb and flow. Tidal range is little more than 1 m between mean lower low water (MLLW) and mean higher high water (MHHW) at the mouth of the St. Marks River.

Field surveys and model applications were conducted on aquatic and terrestrial habitats of St. Marks National Wildlife Refuge in the Big Bend region of northwest Florida. The refuge is situated approximately 20 miles south of Tallahassee and covers parts of Wakulla, Jefferson, and Taylor counties. The total area of federally owned land encompasses 64,599 acres. Of the total acreage, 31,500 acres are open water in Apalachee Bay and 32,082 acres are forest and marsh. The refuge is bordered by Apalachee Bay on the south, Ochlockonee Bay on the west, and the Aucilla River on the east. The reserve was purchased in 1929 and is one of the oldest refuges in the entire refuge system of the U.S. Fish and Wildlife Service.

The refuge landscape is characterized by a relatively low elevation gradient that is intersected by several rivers and a number of freshwater springs and intertidal creeks. Upland pine sandhills drain into wet pine flatwoods and hardwood swamps within the freshwater zone and into tidal salt marsh and mudflats at bay's edge. Seagrass beds are abundant throughout Apalachee Bay, a shallow low-energy system open to the Gulf of Mexico. Elevations of these major habitat types ranges from below sea-level for seagrass, 0 – 2 ft mean sea-level (msl) for salt and fresh marsh, 2 – 4 ft msl for coastal pine, palm, and hardwood hammocks, 4 – 6 ft msl for bottomland hardwood and pine flatwoods, and above 6 ft msl for pine sandhill and oak associations in the higher elevations approaching 40 ft msl. The absence of relief contributes to the largely wetland composite of vegetation types.

11.3 Zonation of Coastal Marsh and Forest Ecotones

Zonation of low marsh habitat at St. Marks NWR is readily apparent with a narrow band of S*partina alterniflora* along tidal creeks, and then a broad expanse dominated by *Juncus roemerianus* that gives way to sand flats sparsely vegetated with succulent species, *Salicornia virginica* and *Batis maritima*. High marsh zonation above the sand flats is generally a diverse assemblage of brackish tolerant graminoids in a fairly narrow band at the ecotone of lowland pine-palmetto forest. Plant height and biomass (*Juncus roemerianus* and *Spartina alterniflora*) varies with inundation and salinity exposure, tallest near tidal creeks and lowest on higher sand flats (Kruczynski et al. 1978). Coultas and Gross (1975) described the soil types and particle size relations in this marsh which vary with elevation and vegetation from coarse-loamy Sulfaquents within low marsh grading to sandy Psammaquents and Haplaquods within high marsh habitats. Interspersed within the salt marsh zones are disjunct pine/palmetto islands from the coastal forest fringe. Island vegetation is a mix of stunted slash pine, *Pinus elliotti,* sabal palmetto, *Sabal palmetto,* saw palmetto, *Serenoa repens,* and associate shrub species. Remnant stumps of pine species and standing dead palmetto trunks are evident in high marsh zones and on small islands within the salt marsh zone (Figure 3).

Jackson (1952) and Kurz and Wagner (1957) noted the threat of coastal erosion and sea-level rise on these same coastal wetlands of the northern Florida gulf coast as evidenced from scoured beaches and remnant pine stumps in salt marsh and tidal flats. Their investigations focused on this coastal reach long before "climate change" was coined to describe the human-induced factors of fossil fuel consumption and rising CO2 that may accelerate or exacerbate global warming trends and sea-level rise. Several zonation and elevation studies have been conducted in this marsh setting denoting the close association of

Figure 3. Photograph of marsh/forest ecotone showing dead cabbage palms trunks in Juncus and high marsh settings of St. Marks National Wildlife Refuge, Florida.

tidal dynamics on vegetation distribution, soils, and growth forms (Jackson 1952; Kurz and Wagner, 1957, Coultas and Gross, 1975, Kruczynski et al., 1978, Raabe et al., 1996, Cahoon et al. 1998, Doyle 1998; Williams et al., 1999). Ramsey et al., (1998) used

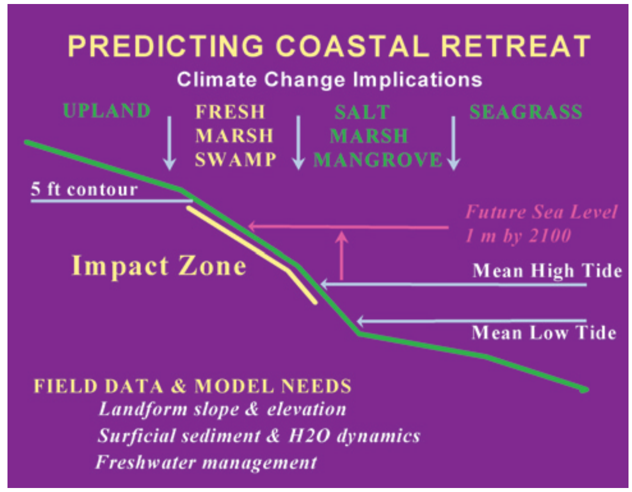

Figure 4. Conceptual model of coastal slope and process of habitat zonation and potential migration and displacement in relation to tidal range and rising sea-level. This graph illustrates the importance of characterizing the landward slope and the lack of readily available data between the 5 ft contour on USGS quadrangle maps and bathymetric data below mean high tide.

satellite and aircraft remote sensing tools to dynamically monitor the coastal flooding extent for specific tidal events to validate and relate surface topography to vegetation zonation. A review has been conducted on coastal marshes of the northern gulf coast by Stout (1984) that illustrates the strong correlation of marsh species zonation with tidal dynamics (Eleuterius, 1976; Eleuterius and Eleuterius, 1979; Hackney and De La Cruz, 1982; Eleuterius, 1984).

The goal of this case study was to develop a spatial simulation model to predict the effects of changing sea-level based on IPCC (1996) climate change scenarios on coastal wetlands of the gulf coast region. A field study was conducted to elucidate vegetation relations with elevation for constructing and validating a digital elevation model of the land surface. A high resolution model of surface topography was needed to predict the rate and fate of coastal inundation from sea-level rise over the next century. Figure 4 illustrates the purpose and process of characterizing the slope of the coastal landform and habitat relations linked with the tidal prism and future sea-level rise. Land elevation and tidal inundation are key factors controlling habitat type and distribution in this coastal environment. Elevation surveys were conducted across the forest/marsh ecotone in various watersheds to test the vegetation-elevation relations under different freshwater and tidal forcing.

11.4 Elevation Surveys of Landform Slope and Vegetation

The ability to predict landward transgression of coastal marsh caused by sea-level rise depends on knowledge of vegetation distribution linked to land elevation. First order benchmarks were used to open and/or close multiple transect surveys using a laser level with millimeter accuracy. Figure 5 shows a surveying crew laying out transects intersecting a typical ground view of the marsh/forest ecotone. Global positioning system dataloggers were used to record real-time differential coordinates at each transect station. Station locations were established every 30-m along a given transect from which land elevation, surface water elevation, vegetation cover and stature were recorded. Horizontal stations were increased to less than 1-m intervals to capture sharp transition zones near tidal creeks, pine-palmetto islands, and at the terrace escarpment delineating the transition between high marsh and forest cover. Field data were verified by constructing histograms of vegetation distribution with surface elevation. Most surveys closed to within 3-mm.

Figure 5. Photograph of surveying crew laying out transects intersecting a typical ground view of the marsh/forest ecotone. Note the stressed canopy condition and dead snags of cabbage palm, hardwoods, and pines along the marsh/forest transition zone.

Field survey results were used to produce proxy elevation contours within the tidal marsh landscape by identifying transition zones of vegetation types on aerial photography and even satellite imagery. Figure 6 illustrates the ranges of species occurrence with elevation and observed tidal datums. Exposed sand flats occupied by *Batis* and *Salicornia* are highly visible on remote imagery and coincidentally occurred at the upper elevations at mean high water (30 – 45 cm, low and high side, NAVD88) based on field results and observed tide tables for the area (See Figure 6). Also highly visible on aerial imagery was the distinct marsh-forest boundary which measured near the elevation of mean higher high water (MHHW, 55 – 60 cm, NAVD88) (See Figure 6). Continuous forest cover was surveyed above 1.1-m NAVD88 that was coincident with height of maximum observed normal tides. The surveyed height of the forest/marsh ecotone and exposed sand flat demarcation were used to create proxy elevation contours to construct a digital elevation model (DEM) of the study area.

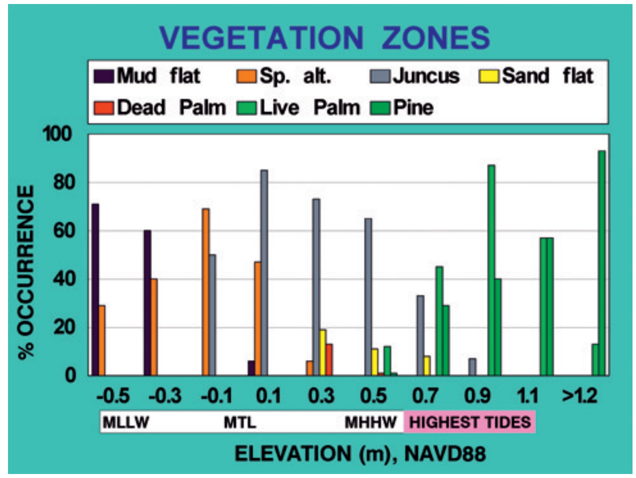

Figure 6. Elevation ranges of vegetative cover and bare substrate in relation to normal tides for St. Marks river expressed in NAVD88. Percent occurrence is based on the frequency of presence in decimeter classes for all transect points surveyed for elevation within St. Marks National Wildlife Refuge, Florida. Tidal range bar depicts height of upper (MHHW, mean higher high water), mean (MTL), lower (MLLW, mean lower low water) and highest observed tide limits recorded for the St. Marks river tide station.

11.5 Development of Landscape Digital Elevation Model (DEM)

A DEM of the study area was constructed to track the process and pattern of coastal inundation over space and time for various projections of sea-level rise. Hypsography and bathymetry of the study area were digitized from a series of coastal map products obtained from USGS 7.5' quadrangle maps (1:24,000 scale) and National Oceanic and Atmospheric Administration (NOAA) hydrographic charts (1:20,000 scale). Contour intervals on standard USGS topographic maps begin at the 5-ft or 1.5-m contour which is well above the marsh system in this locale. Proxy elevation contours based on vegetative features distinguishable on aerial photography and satellite imagery products were digitized to provide intermediate slope contours of the salt marsh system. A DEM was spatially interpolated from the collective contour lines and point data of surface elevations (NAVD88).

A complex TOPOGRID algorithm within the ARC-INFO geographic information system program was used to construct a high resolution, 30-m, DEM of the coastal reach (Figure 7). Classified thematic mapper imagery at 30-m pixel resolution of aquatic and terrestrial habitat at a community level was obtained from the Florida Freshwater Game and Fish Commission in conjunction with the Florida Department of Transportation to provide a habitat layer. Likelihood indices were derived for marsh species and forest cover in relation to land elevation to predict changes in habitat cover with increasing tidal inundation across the simulated landscape.

Model simulations were initialized with present day habitat and tidal conditions (1995). Simulated forecasts of the tidal regime were based on mean annual sea-level for Key West (assumed tectonically stable for gulf coast gages) redundantly repeated to the year 2100. Simulated sea-level rise was incremented to the observed tidal record based on IPCC

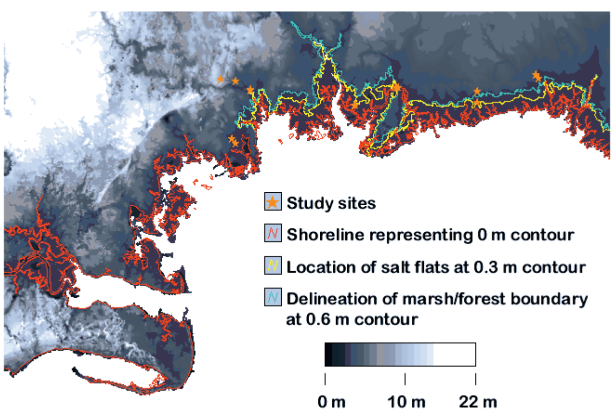

Figure 7. Digital elevation model for Big Bend coastal region encompassing St. Marks National Wildlife Refuge, Florida. Contours denote proxy elevations calibrated for given ecotones based on field survey transects (stars).

(1996) eustatic sea-level rise projections at 15 (low), 50 (mid), and 95 (high) cm. Figure 8 illustrates the modeled low-case, mid-case, and high-case sea-level projections as described for model simulation. The model maintained a register of land elevation, mean tide elevation, and current habitat type for each 30-m land unit (pixel cell) in the landscape template of the study area. This approach is similar to the USEPA Sea Level Affecting Marsh Model (SLAMM) by Lee et al. (1992) and Park et al. (1993) except for the much higher resolution DEM and empirically based habitat tolerance model that dictates habitat succession. The model is updated annually for predicted tide height which is then contrasted with the land elevation of each land unit (i.e., 30-m pixel) to determine flood height or deficit. Flood height is then used to predict favored habitat condition based on probability functions of species and community tolerance to coastal inundation and elevation calibrated from field surveys. In years where flood height exceeds tolerance for the prevailing habitat condition and favors a different habitat type, the model updates the habitat array to reflect a change in ecological succession. Model output consists of pixel counts and hectares of converted habitat, loss and gain, by calendar year.

11.6 Coastal Wetland Habitat Loss and Migration

Sea-level rise was simulated based on a series of case projections, low, mid and high, adopted from the IPCC (1996) for 2000 to 2100 (See Figure 8). At these levels, major portions of the coastal zone in this region will be permanently inundated over the next century, bringing about a migration and loss in the total area and proportion of some habitats. The model incrementally increases the flooding height on an annual basis according to the predicted change in sea-level by year for each sea-level scenario. It determines whether or not habitat conversion and/or loss occur as successive cells from coastal waters exceed the land elevation height of inland terrestrial vegetation and the tolerance of the existing vegetation type for another more tolerant plant cover.

Because of the low relief, model simulations predict significant shoreline changes and flooding of current terrestrial vegetation zones under all three IPCC (1996) sea-level rise projections (Figure 9). Results show that there is a large landbase that will be converted from marsh to open water and forest to marsh (Figure 10). However, because of the slope of the landform, coastal marsh is predicted to increase slightly in land cover as it migrates upslope and replaces existing forest habitat. A significant portion of coastal pinelands will be lost on the order of thousands of hectares that stand at or below the 1.5-m contour by a projected sea-level increase of 0.95-m (high) over the next century (See Figure 10). There will be an effective migration of emergent marsh into forested zones though an overall net loss of terrestrial habitat to an open water environment.

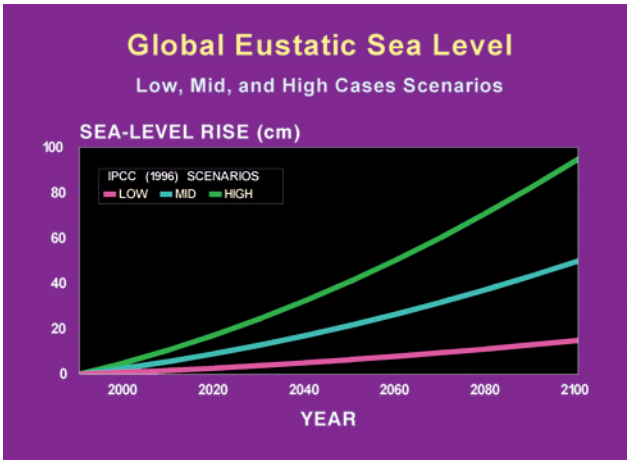

Figure 8. Eustatic sea-level rise projections for scenarios of low, moderate, and high cases based on Intergovernmental Panel on Climate Change (1996).

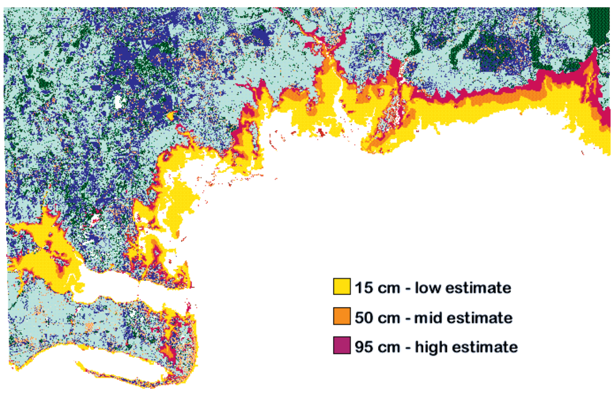

Figure 9. Predicted shoreline changes for IPCC (1996) eustatic sea-level rise projections at 15, 50, and 95 cm by year 2100.

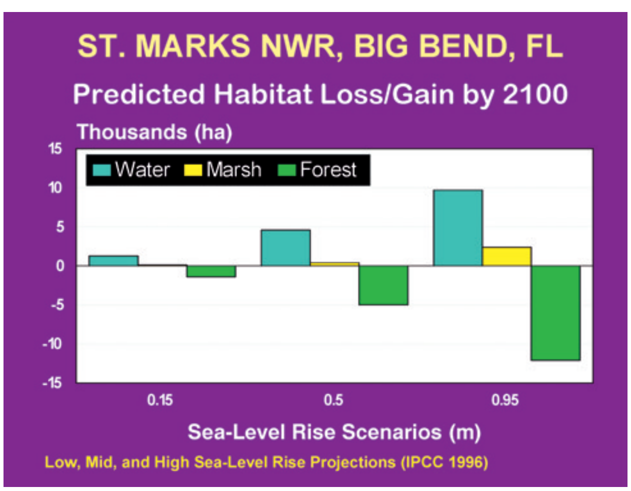

Figure 10. Predicted changes of net loss and/or gain of coarse habitat types, open water, emergent marsh, and forest for low, mid, and high sea-level rise (m) projections by the year 2100.

The use of elevation survey data and surrogate contouring based on ecotone boundaries and tide projections added to the detail and accuracy of interpolating the landform between shoreline and the 5-ft contour and for predicting habitat loss/gain under increasing sea-level conditions. This modeling approach offers a technological tool for research and policy purposes that allows for effective land and water management, risk assessment, and cumulative impact analysis of wetland systems and landscapes.

11.7 Socioeconomic Implications

Projected sea-level rise of any proportion, low or high, will effectively cause coastal transgression and reduce terrestrial habitat within the St. Marks National Wildlife Refuge. Because of its wilderness status and few inholdings, the major loss of lowland pine habitat will have little socioeconomic impact. To the contrary, model predictions for all sea-level rise cases indicate a slight gain in coastal marsh habitat that may actually enhance local fisheries and wildlife benefits. The local economy is modestly dependent on the coastal shellfish industry and a mostly upland pine forest products base. In this particular coastal reach, the U.S. Government is the primary land agent that will effectively lose a significant portion of its conservation investment on the order of thousands of hectares of coastal pine/hardwood habitat. At present, there is a sufficient buffer of extended upland sandhill forest bordering other state and federal forest preserves that these losses may only directly reduce wildlife resources carrying capacity. It is not known whether existing populations of black bear, white-tail deer, avian species, etc., can compensate for habitat losses given more intensive habitat utilization. Usually habitat losses of this scale will effectively reduce the size and security of current mammal populations and perhaps minimal consequences on resident and migratory avian populations because of how they depend on the expended resource.

Population projections for Florida counties are far above national averages. The tri-county area of Wakulla, Jefferson, and Taylor counties is no exception with projected increases of 57%, 38%, and 31% in county populations from 2000 to 2025. Most of this growth will be in and around Tallahassee and outlying populated areas that are far removed from the coast and any likely influence, direct or indirect, on these coastal resources.

11.8 Coping Strategies

Coping strategies may not be warranted given the minimal losses to the local economy and the limited options to remediate the natural process of coastal transgression. Diked systems already exist within the St. Marks National Wildlife Refuge that may be modified to slow or retard coastal transgression. Because of the shallow limestone base with underground channels to coastal waters, it is doubtful that costs and benefits could warrant any hard engineering alternatives to combat sea-level rise. It is also likely that any effective coastal revetment would do more harm than good in the near term by reducing estuary size and function, thus productivity, and spur a negative impact on the local economy.

11.9 Adaptation and Future Research

Unlike some coastal reaches where burgeoning population growth impinges on wetland health and protection, the tri-county region around St. Marks National Wildlife Refuge is still relatively undeveloped and rural. Coastal developments in the region are increasing at a modest pace but are mostly constricted to beach strands on limited stretches given the largely excluded and extensive coastline under U.S. Government protection. There are no significant impediments to coastal wetland migration to warrant consideration. Coastal adaptation strategies may be of nominal value except to determine necessary building restrictions as they relate to potential sea-level rise.

Given the long history of coastal studies relating vegetation cover and changes to tidal influence in this locale, long term monitoring of existing conditions should be implemented to document real-time events that affect coastal retreat. The study area represents a fairly isolated coastal reach largely unaffected by coastal development or upland watershed utilization so as to provide a control site for other coastal contrasts influenced directly by humans and nature. Because of the low relief and open tidal exchange of this low energy coast, this area would be ideal for investigating the contributions of short versus long term fluctuations in tidal behavior and events as related to sea-level rise and coastal transgression. For instance, little is yet known how intra-annual and inter-annual variations in climate and tidal cycles affect forest/marsh retreat and recovery.

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